

Lightweight Mirror Finishing with Magneto-Rheological Finishing (MRF)

presented to:

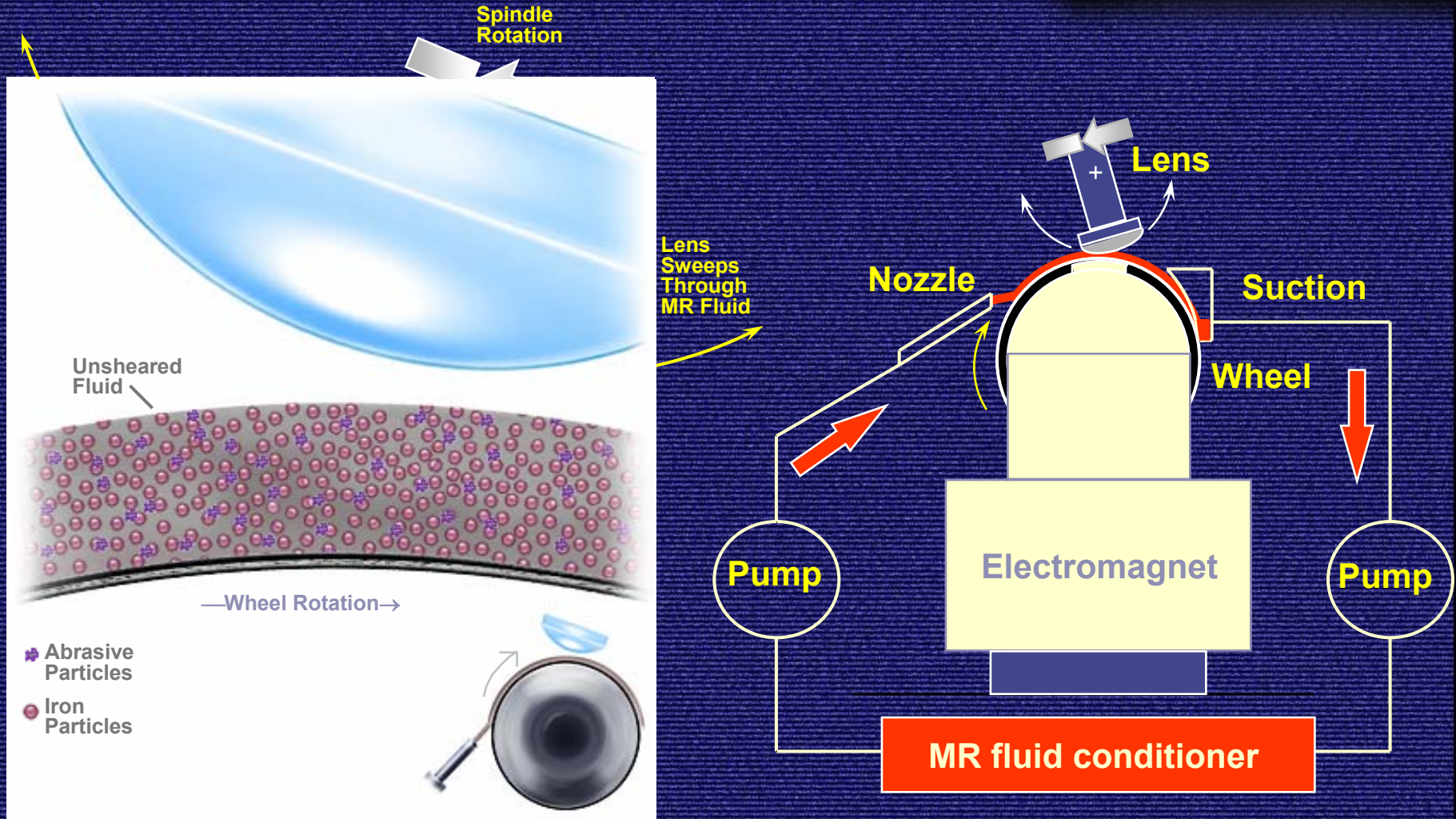
Technology Days in the Government
Mirror Development and Related Technologies
16-18 September 2003 • Huntsville, AL

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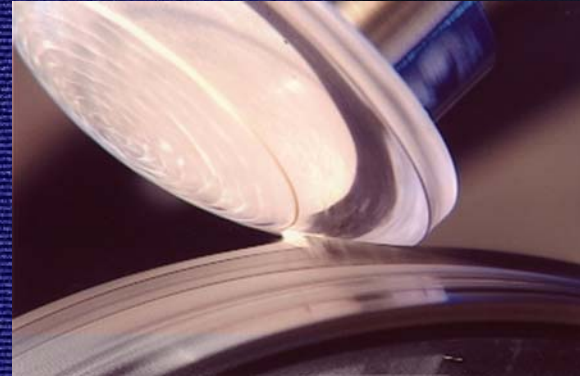
Acknowledgements:
Dr. Larry Matson
MDA SBIR 03-25

MRF – How it Works

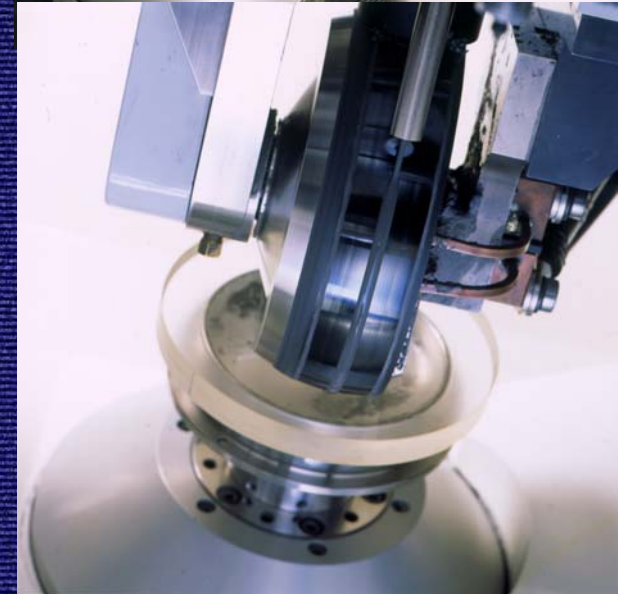
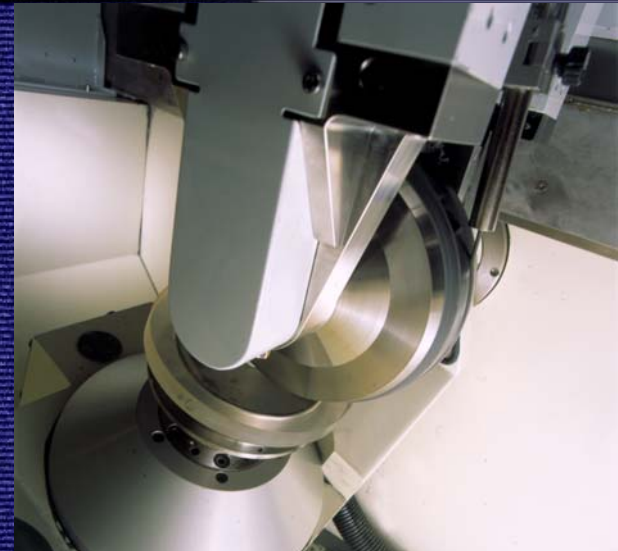


The MRF polishing tool:

- never dulls or changes
 - is interferometrically characterized
 - is easily adjusted
 - works on complex shapes (flat, sphere, asphere, cylinder...)
 - has high removal rates
 - applies very low normal load on abrasive, improving surface integrity
 - removal based on shear stress
-
- These attributes lead to a production oriented, deterministic, computer controlled polishing and figuring technique.
 - Production proven: more than 80 machine worldwide



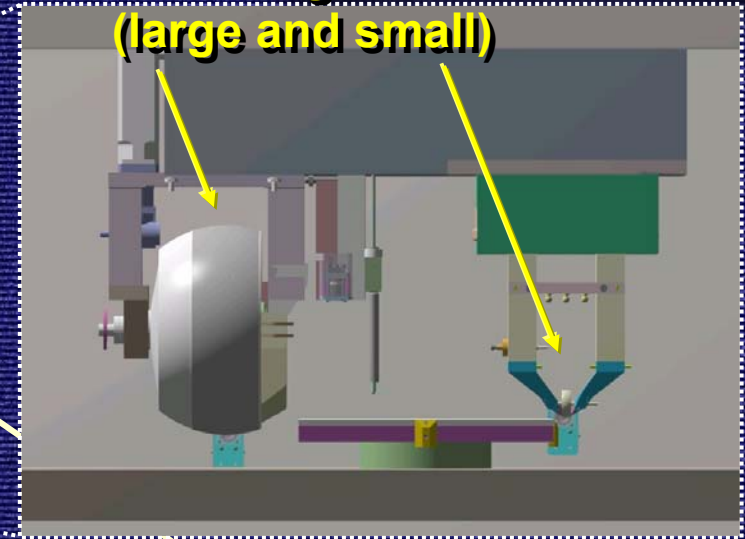
Q22-400X MRF System



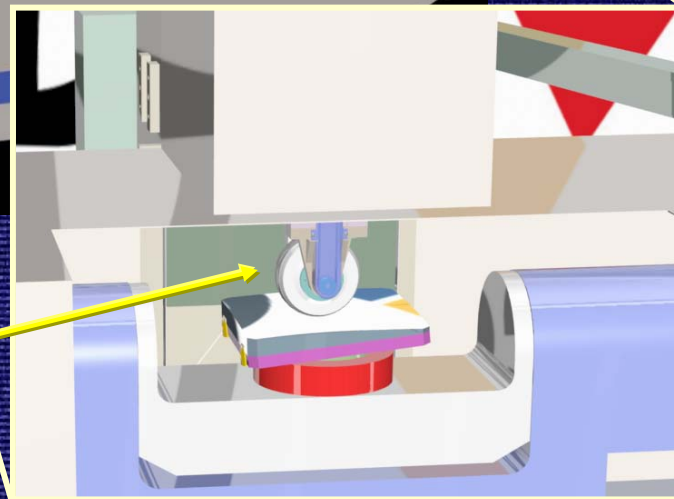
Q22-750 with one or two wheels



**Two wheel configuration
(large and small)**



**One wheel
configuration**



**Various
machine
configurations
available**

Advantages of Using MRF to Finish Lightweight Optics

- MRF is insensitive to small changes in distance between workpiece and wheel surface.
- Contact area can be tailored to fix errors such as quilting.
- High removal rate can be achieved by adjusting system settings.
- MRF is already used in production to polish aspheric surfaces up to 400 mm.
- Current efforts are being made to increase the part size that can be polished with MRF with development of 750P platform (approx. 0.5 m x 1.0 m), and machine for 2-4 meter optics under study.

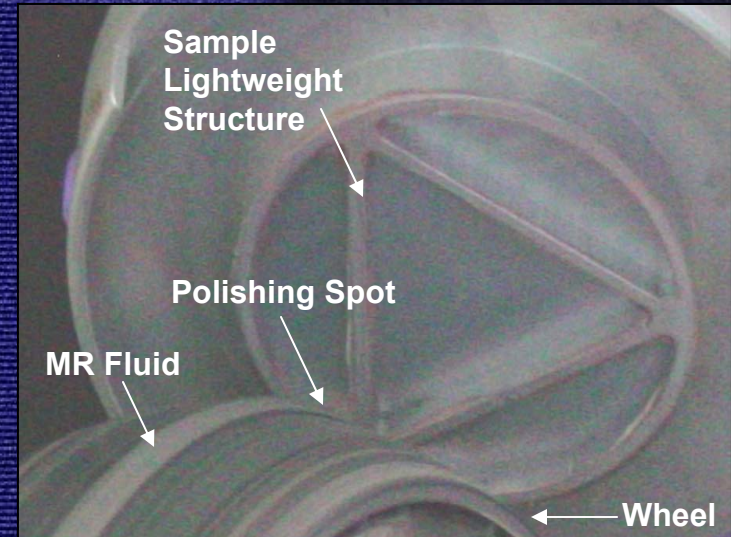
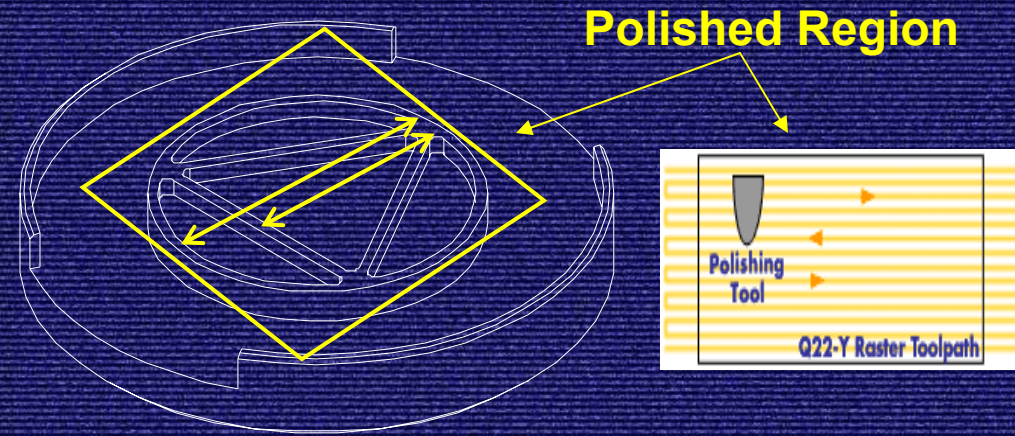


Model Development



- We can directly measure the pressure distribution and contact area of the MRF “spot”
- Model a lightweight cell as a circular cell with fixed boundary conditions
- Estimate face-sheet deflection by modeling MRF spot as a uniform pressure applied over a circular sub-aperture contact zone
- Can apply model for different cell sizes, face-sheet thickness, materials and MRF process conditions

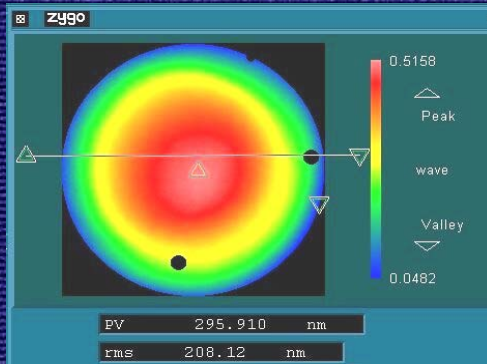
Experiment #1:



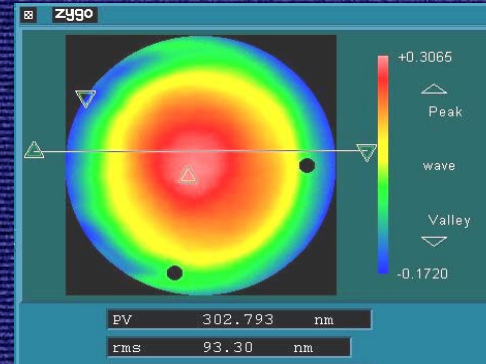
Circular support = 60 mm diameter
Triangular Support = 40 mm apex to flat
70 mm square polished with raster toolpath

- UV cement 1 mm thick FS disc on support and polish with MRF
- Used typical MRF process settings
- A uniform 1 μm thick layer of material was removed over a 70 mm square area using raster tool motion
- Medium to aggressive plunge depth (I.e. realistic polishing conditions)

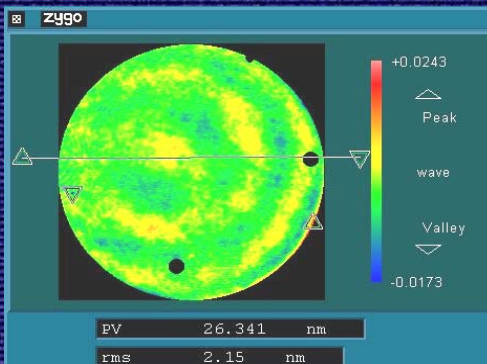
Experiment #1: Continued



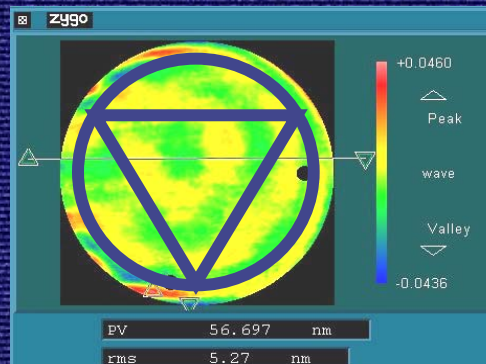
Initial



1 μ m uniform removal



Initial – 36 Zernike terms removed



**1 μ m uniform removal –
36 Zernike terms removed**

No quilting effect
was observed

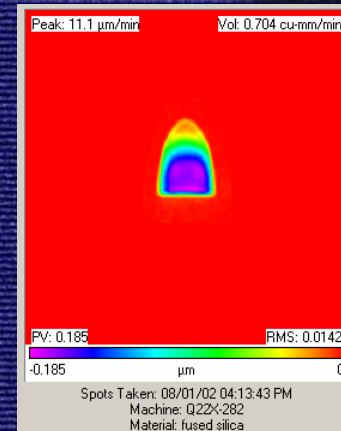
Removal rate and roughness

High removal rate dependent on:

- Material: FS, ULE, Zerodur, Si, SiC...
- Process parameters
- Machine/wheel size

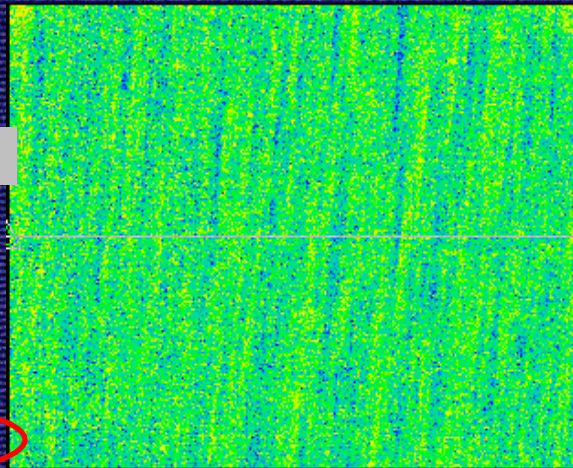
Roughness

- MRF *smooths* most materials
- E.g. fused silica results:

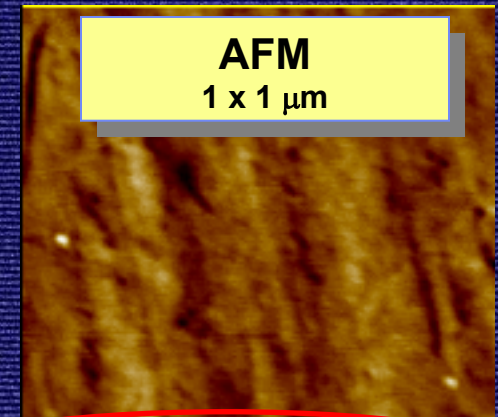


High Pass Filter (FTT Fixed – 12.5 1/mm)

Rmax	44.692	\AA
Ra	2.829	\AA
Rq	3.575	\AA



New-View 5000
359 x 270 μm

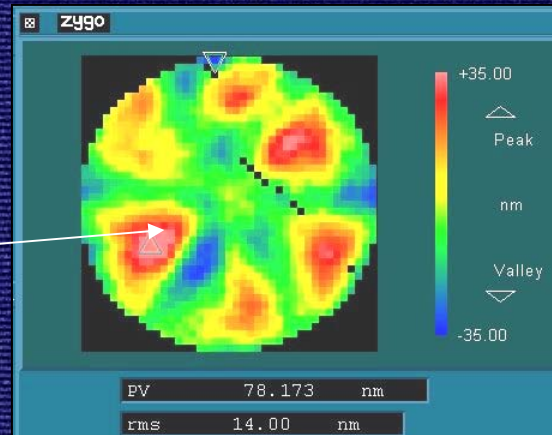
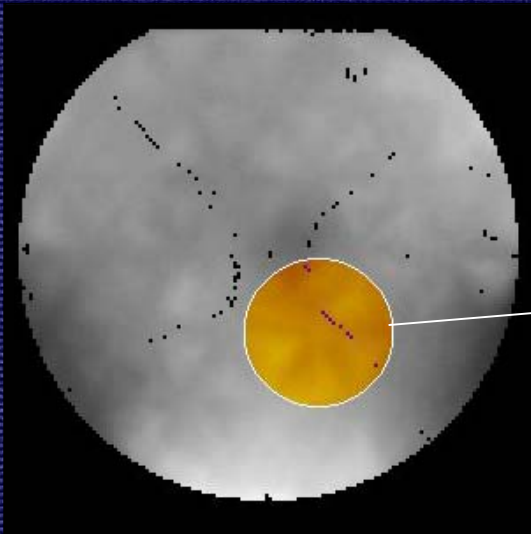


AFM
1 x 1 μm

Img. Rms (Rq) 0.176 nm
Img. Ra 0.136 nm
Img. Rmax 1.884 nm

Experiment #2:

Cryogenic Quilting Map

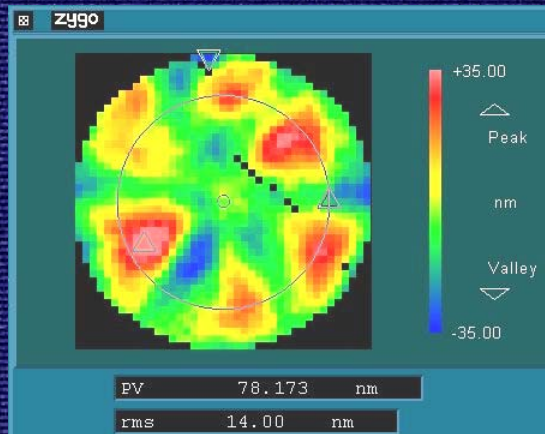


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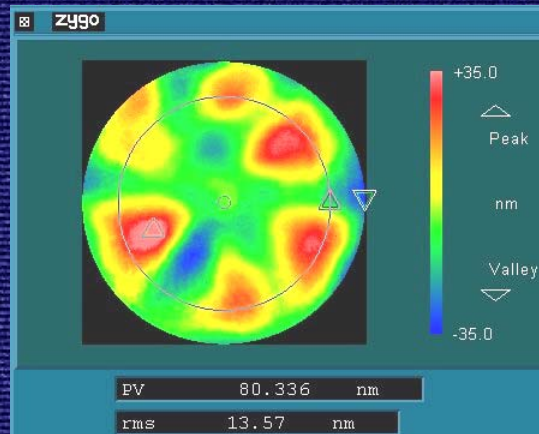
Dr. Phil Stahl
James Hadaway
Ron Eng

- QED has received a quilting pattern generated from NASA/UAH cryogenic metrology tests of 0.5 m demonstrator mirrors
- To demonstrate feasibility of using MRF to remove quilting patterns we did the following:
 - A 150 mm subsection of the metrology file was extracted
 - The global error was removed from this subsection (to evaluate the ability to remove features on the length scale of the cell size)
 - This metrology was used as input to an MRF polishing run to print the inverse of the features *into* a flat glass part

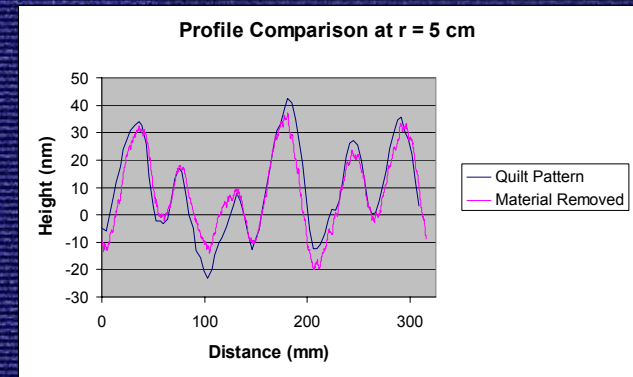
Experiment #2 - Continued



Quilt Pattern
145 mm CA
PV = 78.2 nm
rms = 14.0 nm



Material Removed
145 mm CA
PV = 80.3 nm
rms = 13.6 nm

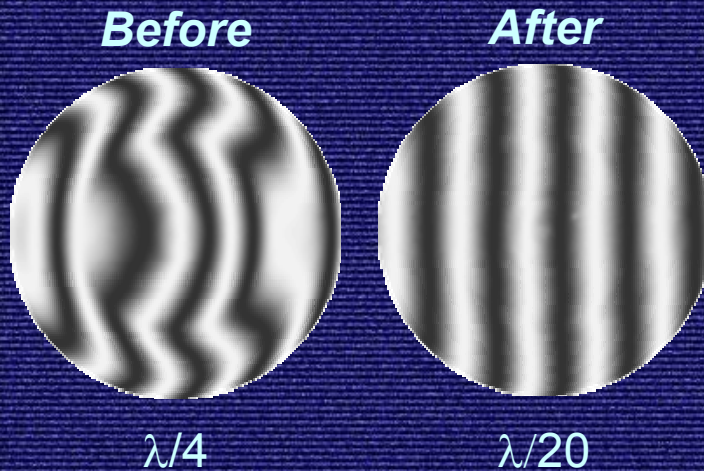


**Profile Comparison at
5 cm radius**

- “Material Removed” is an inverted map of the pattern printed into the surface – **after a single polishing iteration**
- MRF was able to reproduce the pattern taken from the quilting map
- Agreement of surface profiles, each taken at a radius of 5 cm, further demonstrates the validity of the approach
- If MRF can “print in” such features, it is very likely it can remove them
- The next step would be to correct errors on a real lightweight mirror

Conclusions/Next Steps

- **MRF deterministic polishing process**
 - High material removal rate and convergence rate
 - Can improve roughness on most materials
- **Process scalable to larger size optics**
 - 200, 400mm standard sizes
 - 500-1,000mm being built
 - 2-4 meters currently under investigation
- **For light-weighted optics:**
 - Unique MRF attributes and initial results indicate ability to polish lightweight mirrors without inducing quilting and/or fix existing errors such as quilting patterns
 - Continue to investigate material compatibility and validate polishing process



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